DUST CONTROL IN MINING, TUNNELING, AND QUARRYING IN THE UNITED STATES

BY C. W. OWINGS

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SUMMARY

Available literature published or abstracted in 1953 and 1954 relating to dust prevention and suppression has been summarized and reviewed in this report, and unpublished information also is included to outline current practice for those interested in dust control in and around mines, tunnels, and quarries.

More and more companies are realizing the value of controlling dust by incorporating suitable methods and devices in the planning stage. In preparation and crushing plants preliminary tests have been made of the fine materials to determine the best type of dust-control equipment to use, and the details of the quantities of air, the number of sprays, the dust-allaying fluids, and the location of hoods or enclosures have been determined in advance. Such planning has paid for itself in more effective control. Similar planning in a tunnel resulted in healthful conditions and low dust concentrations.

In underground work in mines and tunnels dust control has been centered on better wet drilling and pneumatic collection of dust during drilling. Some of the newer methods of roof drilling in coal mines have featured use of a tube around the drill steel through which the dust is drawn; extracting drill cuttings through hollow drill steel; and combining rotary drills with a positive-displacement, electrically driven pump, and collecting hood. Water infusion has been tried, but it has been adopted in only one mine in the United States. Attention has also been given to better ventilation as a means of dust control, especially with continuous-type mining machines. An exhaust fan and tubing were tried in one mine.

Probably the greatest interest in the dust problem has been in sampling, especially with the new molecular membrane filter. Other materials, such as Fiberglas, have been investigated also. Development of less fatiguing methods of counting dust has brought out several suggested methods. A so-called absolute method consists of collecting dust on a molecular filter, photographing the dust in an electron microscope, and then measuring the particles projected on a ruled screen. Another method, called the most-probable-number method, reportedly has an accuracy close to that of conventional counting. Sampling instruments that have been improved include a rotating and oscillating thermal precipitator and a portable electrostatic precipitator that collects samples on glass or metal slides, has a smaller, lightweight head, and operates from 100 volts a.c. or 6 volts d.c. power. A five-stage cascade impactor has been developed in which properly sized openings give high collection efficiency.

State laws provide compensation for occupational diseases, including silicosis and asbestosis, except for Mississippi and Wyoming. All but 11 of the 46 States with occupational disease laws provide for other pulmonary dust diseases.

INTRODUCTION

The International Labor Office, established in 1919 and a Specialized Agency of the United Nations since 1946, met at Geneva, Switzerland, December 1-17, 1952, when experts on the prevention and suppression of dust in mining, tunneling, and quarrying from 20 countries gathered to report on progress and steps being taken to prevent and to suppress airborne dust in mines, tunnels, and quarries. At the meeting it was recommended that information and experience should be exchanged among countries interested in preventing and suppressing dust in these industries. For this purpose a central organization was designated to collect and distribute information of an administrative, technical, and scientific character. Each country concerned communicates such information and data as become available annually to this central organization. Two reports have been submitted to this office covering the calendar years 1953 and 1954. This circular is a combination and condensation of those parts of these reports that pertain to dust control, dust-control statistics, and pertinent legislation.

It discusses briefly the subject of prevention and suppression of airborne dusts in mines, tunnels, and quarries and points out the problems involved.

PREVENTING DUST FORMATION AND SUPPRESSING DUST AT SOURCE OF FORMATION

Preventing and suppressing dust in a mine, quarry, or tunnel require careful evaluation of the potential dustiness of an operation at the time a new project is begun or modernization of existing operations and buildings is initiated. Careful planning can save time and money, as well as provide an atmosphere essentially free from harmful dusts.

The International Labor Office (31)[2/] recommends that, in planning any new mining, quarrying, or tunneling operation, due consideration should be given at the outset to means of preventing and suppressing dust, so that the mining, processing, and handling of a mineral or rock will reduce the production of dust to a minimum. The free fall of material both at the face and during transport should be reduced also to a practicable minimum.

COAL MINING

Working Methods

Dust can best be prevented by careful planning of each new mining operation and each new section of a mine. New equipment should be investigated to determine if it can form harmful quantities of dust and, if so, what means the manufacturer has taken to prevent or control formation of dust. In laying out a mine the ventilation should be studied carefully so that enough air will reach each working place to dilute any dust formed below the recommended maximum allowable concentration and to carry such dust where it will pass over the fewest possible number of employees.

In the Pennsylvania anthracite region a dust-control engineer assists anthracite-mining companies to control dust. He states (16) that one of the most important tasks of a dust-control engineer is to make the underground workers understand the hazard of breathing dust and to gain their cooperation in using control measures.

At the time his article was written there were six "well-equipped dust laboratories in the anthracite region." In these laboratories 18 trained engineers and

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[2/] Underlined numbers in parentheses refer to items in the bibliography at the end of this report. Pages cited refer to the item and not to this publication.

technicians were employed to sample dust at underground dust-producing points and to compile records and report conditions to management. They made recommendations for installing proper control systems and gave advice on the most suitable equipment for the type of mining to be done.

One of the engineers of an anthracite company (40) describes how the dust-control program has benefited his company. The dust hazard is accentuated by the fact that a number of haulage and drainage tunnels have to be driven through rock to pumping stations. As the thicker coal beds were worked out and the thinner coal beds were opened, top and bottom rock had to be removed to provide headroom. The program provides for complete dust surveys in every working place, and steps have been taken to correct conditions where dustiness was over maximum allowable concentrations.

The need for research on fundamental factors relating to control of dust has been emphasized by Westfield (53). Part of this research must fall on the engineering staff and dust-control engineers, who must make on-the-job tests under actual mining conditions. Each mine presents special problems that must be solved in that mine. A dust-control engineer should be familiar with the mechanisms of dust formation and basic principles of prevention and control. Observations as to where the control system is allowing dust to escape into the air will help him designate where additional sprays may be needed or an alteration should be made in a dry-dust-collecting system. Trial of different types of equipment, such as new types of bits, new types of drills, water infusion, different styles of conveyors, different height of cutting, and a host of others may solve a difficult dust problem. Westfield also brings out the need for frequent surveys of dust concentrations to evaluate the performance of control measures, rather than relying solely upon installation of recommended methods or procedures.

The remodeling of a cleaning plant of a coal mine in Kentucky is an example of prior planning to help in dust control. Edwards (18) describes a dust-collecting system that was planned for installation at this mine. A wet-type inertial cyclone collector was to be placed directly over the washer sludge tank, and the trapping medium will be water continuously circulated from the clarified portion of sludge water. The collector will be connected by ductwork to collecting hoods placed at seven strategic points throughout the plant. These points are: The discharge end of the run-of-mine conveyor; the feeder and the first 3 feet of the primary scalper; the first 3 feet of the secondary scalper; the conveyor discharge into the washer feed conveyor; discharge points of 3 vibrating screens; the primary crusher; and the recirculating crusher. Dust is cleaned from the plant floor, ledges, and machinery with a 3-hp. vacuum cleaner. Dust control now includes a wetted-water feeder that supplies sprays at the car dump, belt discharge, and two crushers.

Drilling

Research is needed to determine the combination of equipment and practices that will prevent dust formation during drilling or reduce it to a minimum. Preliminary investigations of drilling coal-mine roof in the United States indicate[3] that under test conditions sharp bits apparently form less dust than dull bits, which tend to grind and make finer dust. This has been observed also when a hard streak is encountered during drilling. Instead of cutting out chips, the rock is ground into fine particles. Hard-tip bits should be investigated. The general opinion among American mining men is that hard-tip bits, generally tungsten carbide, cut faster and produce less dust than standard steel bits, probably because they remain sharp longer than steel bits.

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[3] Owings, C. W., unpublished data.

Mine operators are asking for faster and faster drilling speed. Although this can be provided by drill manufacturers, it has been observed that, with the new-type hydraulic rotary drills holes can be drilled faster by applying greater pressure and rotating the drill at slower speed. Bureau of Mines tests have shown that, with hydraulic rotary drills, the speed in soft shale can be as much as 14 feet a minute. The manufacturers claim that such drills can advance 20 feet a minute.

The fastest rate of drilling under limited test conditions was obtained with a 2-inch bit, and the rate was up to 50 percent higher than when 1-1/4-, 1-3/8-, and 1-3/4-inch bits were used. Presumably the larger bit gave greater clearance around the skirt, resulting in a freer flow of fines. This undoubtedly contributed to the higher rate of drilling.

Drilling in coal mines, especially for roof bolting, presents a constant danger from dust. Wet drilling has been used, but in some mines there are many drawbacks to using water. Some mine-roof rock expands when wet, which might result in falls of roof during drilling or possibly around the bolts after bolting has been done. Most holes are drilled essentially vertical, and the water runs down on the driller and into the drill chucks. To overcome these difficulties, the trend is toward dry drilling using dust collectors (see figs. 1, 2, and 3). During 1953 seven dust collectors were approved by the Bureau of Mines for use on percussion-type pneumatic drills, for rotary drills, and in hydraulic rotary drill assemblies. To pass the Bureau of Mines permissibility tests a collector must be able to keep the dust concentration below 10 million particles per cubic foot of air.

Some drilling in rock in coal mines is done dry because it is considered that the drilling is done only intermittently or possibly for a few minutes each shift. A study to determine the exposure under these conditions has been reported by Owings and Johnson (45). Dust concentrations ranged from 25 to 4,531 million particles per cubic foot of air. With ventilation conducted near to the working face, the average dust concentration was 488 million particles per cubic foot; but, when the ventilation was not conducted to the face, the average concentration was 587 million dust particles per cubic foot. There is danger not only for the drilling crew but also for men working downstream on the air current. During drilling where ventilation was conducted to the drill, the average dust concentration was 488 million particles per cubic foot, compared with 83 million 50 feet downstream or about 16 percent of the concentration of dust at the drill. The concentrations at the drill 11 minutes after drilling averaged 15 million particles per cu. ft. compared to 9.7 million particles per cu. ft. 50 feet downstream 10 minutes after drilling stopped.

During drilling in drawslate the exposure per shift was from 19 minutes to 2 hours and 36 minutes, and for top rock exposure ranged from 7 minutes to 2 hours 29 minutes. The time was so variable and the dust concentrations were so high that even for so-called short-period drilling it was considered necessary to provide dust-control measures.

A limited number of tests indicate that auger or conveyor-type drill steel tends to form less dust than round or hexagonal steel. These observations were made when a dust collector was used; with a different collector different results might be obtained. This condition needs to be investigated further.

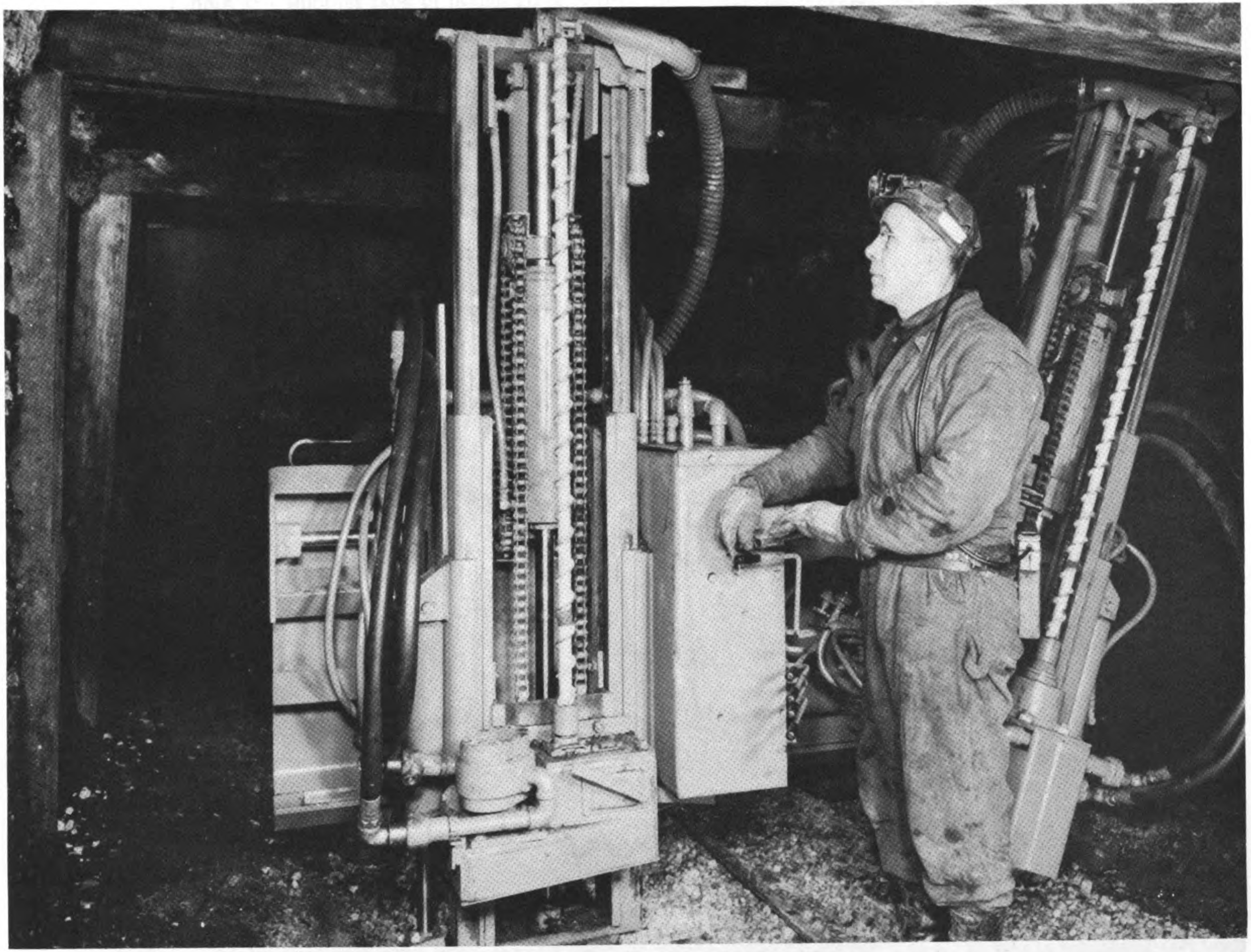

Figure 1. - Permissible roof-bolting drill with integral dust collector. Device works satisfactorily in vertical or angle holes.

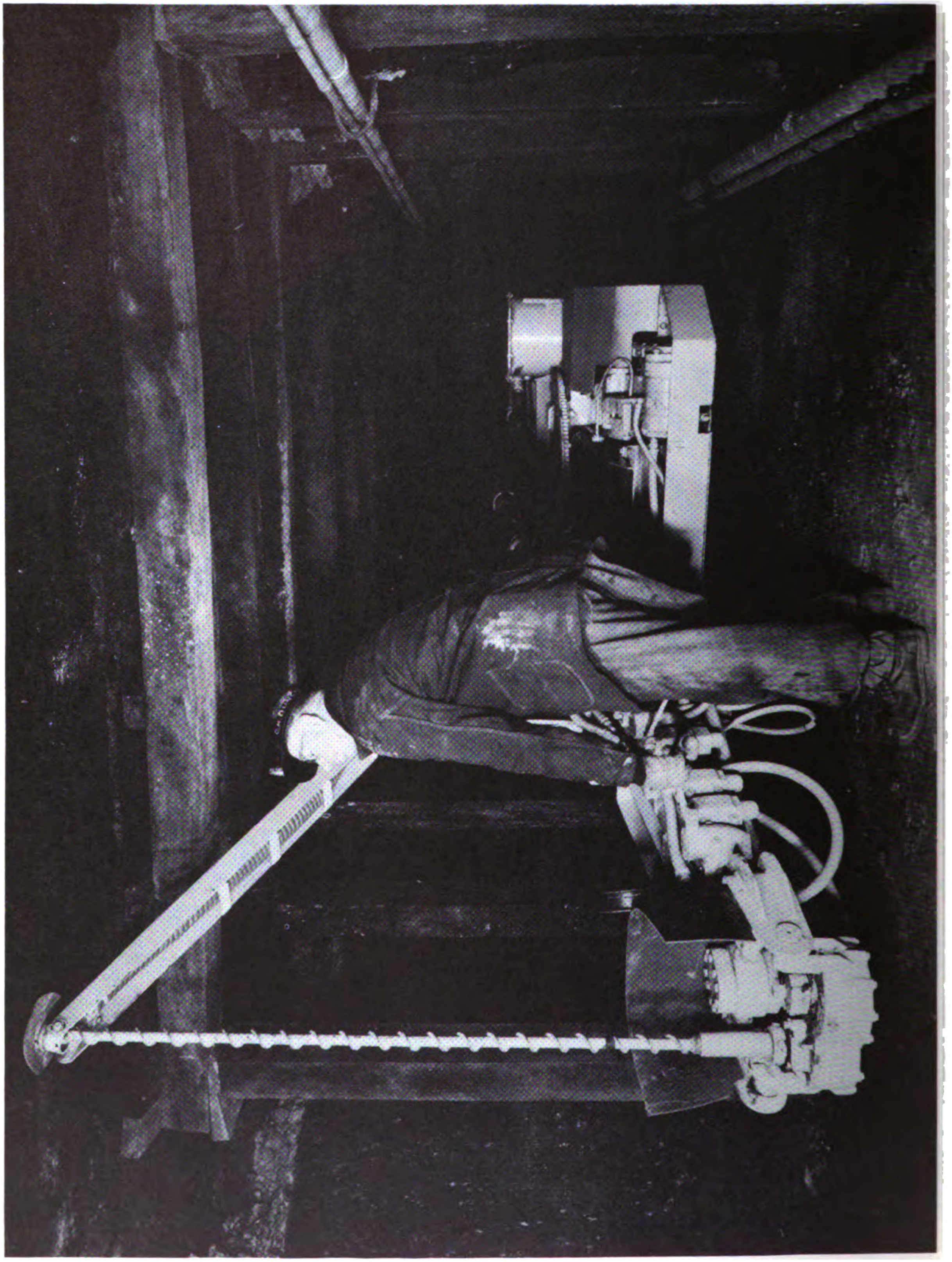

Figure 2. - Another type of permissible roof-bolting drill with integral dust collector.

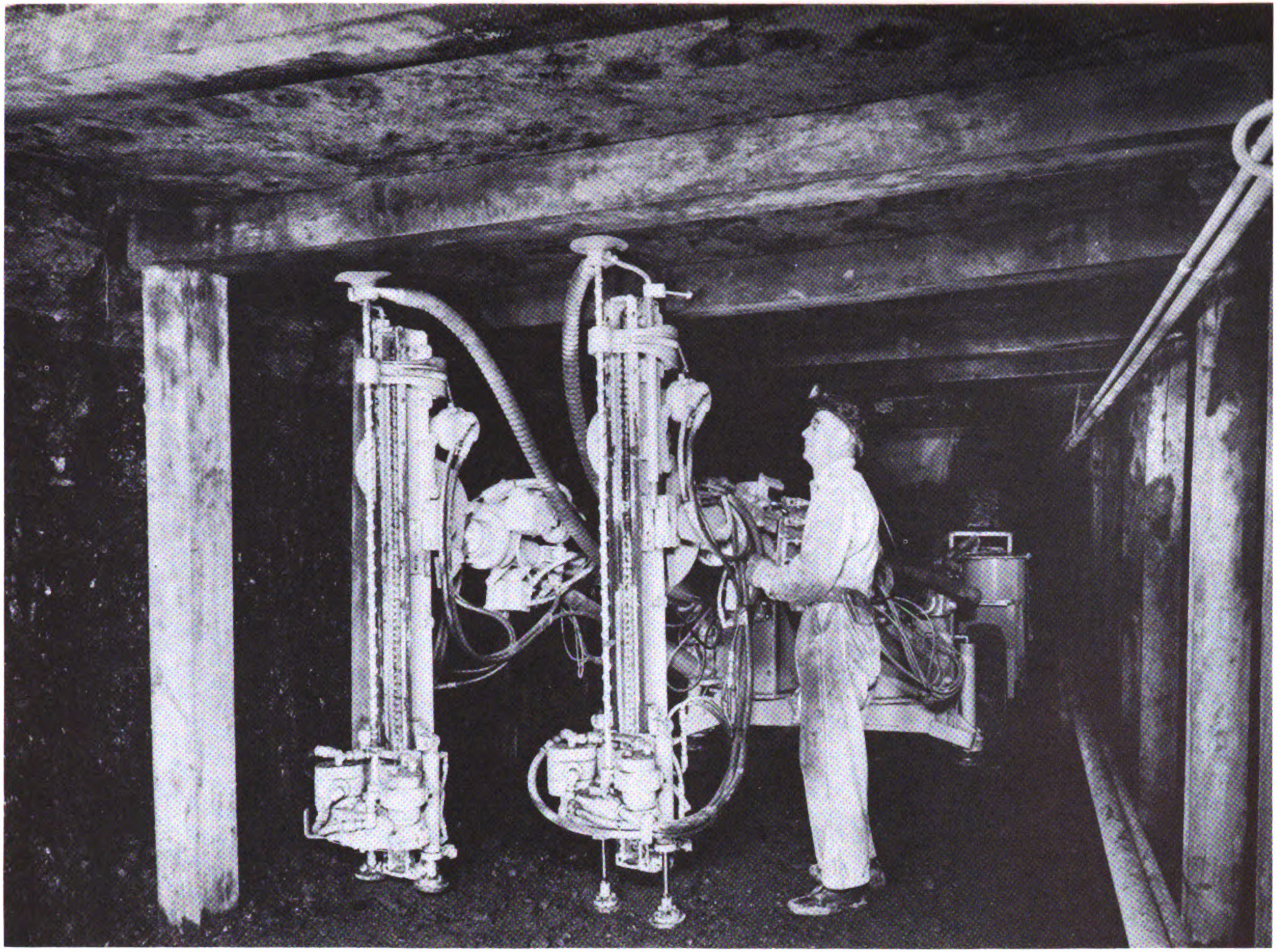

Figure 3. - Permissible two-drill roof bolting unit with integral dust collector. Dust can be collected simultaneously from both drills.

In coal mines use of dry-type collectors continues to be the main method of controlling dust while holes are being drilled in rock for roof bolting. During 1954 the Bureau of Mines approved 10 types of dust collectors of the eductor and positive-displacement-pump types. The method of collecting the dust varied, however. One manufacturer provided a tube for the drill steel with a connection at the bottom of the tube that was attached to the top of the shank. The dust was extracted through the space between the tube and the drill steel. The air was exhausted by an eductor. An English-type drill was approved that extracted the dust through the hollow drill steel.

Difficulties have been experienced in some mines when pneumatic collectors are used if insufficient air is supplied to the drill. This is one of the reasons that Bureau of Mines Permissibility Schedule 25 specifies that all combined units must be tested. It has been found that units that perform adequately under test conditions do not always collect the dust effectively when used under different conditions than those for which they were designed.

Some mining companies are experimenting with collectors built in the mine machine shops. One such unit is reported operating in a Kentucky coal mine (18) where a gravity unit is used with a hydraulic rotary drill. Its performance under mine conditions was not reported. During 1954 development work was done on a bucket-type collector which fits on the drill steel. This has promised to be effective. Work was also done on a collector with a positive-displacement pump for collecting dust simultaneously from two drills.

Considerable interest is shown in combined units with rotary hydraulic drills having an integral dust-collecting unit. It is believed that more and more drills in future will be of this type, where they can be used effectively. In low coal there will be continued demand for the stoper-type units.

Some mine operators prefer dust collectors, even where water is piped into the mine. A mine in Colorado (11) exemplifies this practice. Roof is drilled with a compressed-air-driven stoper, and the dust is collected by a Bureau of Mines-approved dust collector. The collecting box is mounted on a jack close to the drill, and the dust is drawn through filter-cloth baffles that extract most of the dust.

The rapid increase in dry dust collectors has presented a new problem. They will collect the dust when the collecting head is maintained properly and when the filter element is kept clean. Evidently, where supervision is lax the filter element clogs and becomes filled with dust; but the driller continues to drill, allowing harmful concentrations of dust to fill the air around the drill. The dust should be removed according to the manufacturer's instructions. The filters need to be cleaned in some machines by shaking by hand. Failure to observe these necessary precautions may destroy the effectiveness of a collector. Disposal of the dust after it is collected should receive careful consideration. Measures should be taken to prevent the dust from becoming airborne again; it should be removed in dust-tight containers, in the form of mud after wetting, or by other suitable methods.

A survey of dust-control practices in 1954 (1) indicated that about two-thirds of the bituminous-coal mines used dust controls on drills; however, dust was visible during drilling in 1 out of 5 drills. Only about one-fourth as many controls were provided for rotary drills (15.1 percent) as for percussion drills (62 percent).

In anthracite mines rotary drilling was practiced in 169 mines, but no controls were used on these drills in 152 of these mines; dust collectors were used in 5 mines; and wet drilling was used in 10 mines. Visible dust was observed in 3 of these 15 mines during rotary drilling. Controls were used in 83 mines during percussion drilling, dust collectors being used in 15 mines and wet drilling in 68 mines. Apparently wet drilling was more effective than the dust collectors used, as dust was visible in 67 percent of the mines during percussion drilling with dust collectors and in only 1.5 percent of the mines where the drilling was done wet. This ratio is essentially the same for all drilling, as dust was visible in 55 percent of the mines using dust collectors and in only 3.8 percent of the mines when wet drilling was practiced.

Water Infusion

Water infusion generally has been considered unsuited for United States coal mines; however, this method of suppressing the dust was tried in Utah and reportedly proved successful (32). Preliminary tests were made in a West Virginia coal mine, but difficulty was encountered in drilling in crushed pillars.[4/] It was demonstrated, however, that the coal could be infused with water and that dust formation could be minimized. It is believed that water infusion could be used in many coal mines in the United States.

Some research and testing of water infusion in coal mines was still in progress in 1954, but results have not been made public. In one coal bed water infusion was tried to soften the coal in a longwall face where a cutter-loader type of machine was used, but when a pressure of about 100 p.s.i. was reached, the water was lost owing to leakage through cracks or cleavage planes.

Coal Cutting and Loading Machines

The earliest method of dust control on mine equipment was application of water on the cutter bar of mining machines. Studies have been made that have shown the best types and locations of spray nozzles or other control devices on equipment. In spite of this knowledge, in such large coal-producing States as Pennsylvania and West Virginia only about 14 to 15 percent of the mines practice dust control while cutting coal.

Even where water is used, in some mines the hazard of pneumoconiosis still exists, especially where high-speed top-cutting machines are used. More research is needed to determine the water pressure best adapted to certain sprays and, on some types of machines, the type and location of additional sprays.

The type and condition of the machine bits also affects the amount of dust thrown into suspension. Tests[5/] were made using alloy bits, hard-tipped bits, and hand-sharpened steel bits. The hard-tipped bits formed 38 percent more dust than the alloy bits tested, and the hand-sharpened steel bits formed 49 percent more dust. Dull alloy bits liberated 52 percent more dust than the sharp alloy bits, and dull, hard-tipped bits formed 13 percent more dust than the same bits when sharp under similar conditions. When a clay vein was cut, 85 percent more dust was formed than during normal cutting of coal. These were preliminary tests, and the relation of alloy to hard-tipped bits may not necessarily hold true for other hard-surface bits or inserts.

[4/] See footnote 3.
[5/] See footnote 3.

At some plants and coal docks railroad cars are dumped quickly, at times the whole car being turned over and the entire load dumped at one time. This releases large, dense clouds of dust. Unless controlled the dust can become a health hazard as well as a nuisance in the neighborhood. The dust can be controlled by sprays, but usually water alone will not allay the dust. Best results have been obtained by adding a suitable wetting solution to the water.

At a coal dock Harmon[6/] made some tests where men were exposed to airborne dust. At this dock railroad cars were hoisted about 35 feet vertically and rotated about 90° on their horizontal axis, and the coal was allowed to fall onto the lip of a converging steel chute. Spray nozzles were arranged so that the spray covered the thin layer of coal as it fell from the tilted car into a chute. Fourteen nozzles were mounted across the upper edge of the covered chute and four nozzles on each side of the chute entrance. Flat or sheet sprays were mounted along the top of the chute opening, and solid-cone sprays were mounted at the sides and the corners. The pump had a capacity of 300 gallons per minute at a pressure of 108 pounds per square inch. The average dose was 115 gallons (in 20 seconds) per car. This would be equivalent to adding 0.68 percent moisture to the coal. The water had a wetting solution added to it in the proportion of 1:750. Dust counts showed low concentrations, 5 of them less than 1 million particles per cu. ft.; at the dustiest point, on the tipple platform by the end of the car dumper, the air contained 25.9 million particles per cu. ft. Men were not required to work there; otherwise, it could have been protected by a suitable spray or sprays.

A survey of dust-control practices in United States coal mines (1) indicated that dust controls were used on mining machines in 16.2 percent of the bituminous-coal mines. The percentage of bottom-cutting machines having dust controls ranged from 3.5 percent for mines employing less than 15 men to 27.5 percent for mines in which 100 or more men were employed. Visible dust was observed in nearly half of these mines having controls. Greater attention was given to dust control in mines where cutting was done other than at the bottom. The controls range from 19.2 percent for mines with less than 15 men to 74.5 percent for mines with more than 100 men; however, visible dust was reported in 62.5 percent of these mines; there was a deficiency in 70.8 percent of the mines having 15 to 99 men. In the larger mines nearly half of the mining machines were provided with dust-control devices or measures, and only about half of these were effective. Water is piped to the working places in many mines, especially in the larger ones, such as a Colorado mine (11) where special couplings are used for speed in installing and dismantling pipes.

Continuous mining-type machines are capable of liberating dense concentrations of coal dust, frequently billions of particles per cubic foot of air (33), when no control is provided. At an experimental laboratory with conventional mining equipment without dust-suppressive measures, dust concentrations were of the order of 390 million particles per cu. ft. while cutting, 171 million particles per cu. ft. during drilling, 441 million particles per cu. ft. during and after blasting, and 87 million particles per cu. ft. during mechanical loading. With a continuous-type miner, the concentration was 284 million particles per cu. ft. when no controls were used and 96 million particles per cu. ft. when water sprays were used at a pressure of 380 p.s.i. (see figs. 4 and 5).

Kelley (33) remarks that:

> Water sprays can be used to advantage to promote the circulation of air toward the face and from top to bottom along with the falling coal

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[6/] Harmon, J. P., unpublished data.

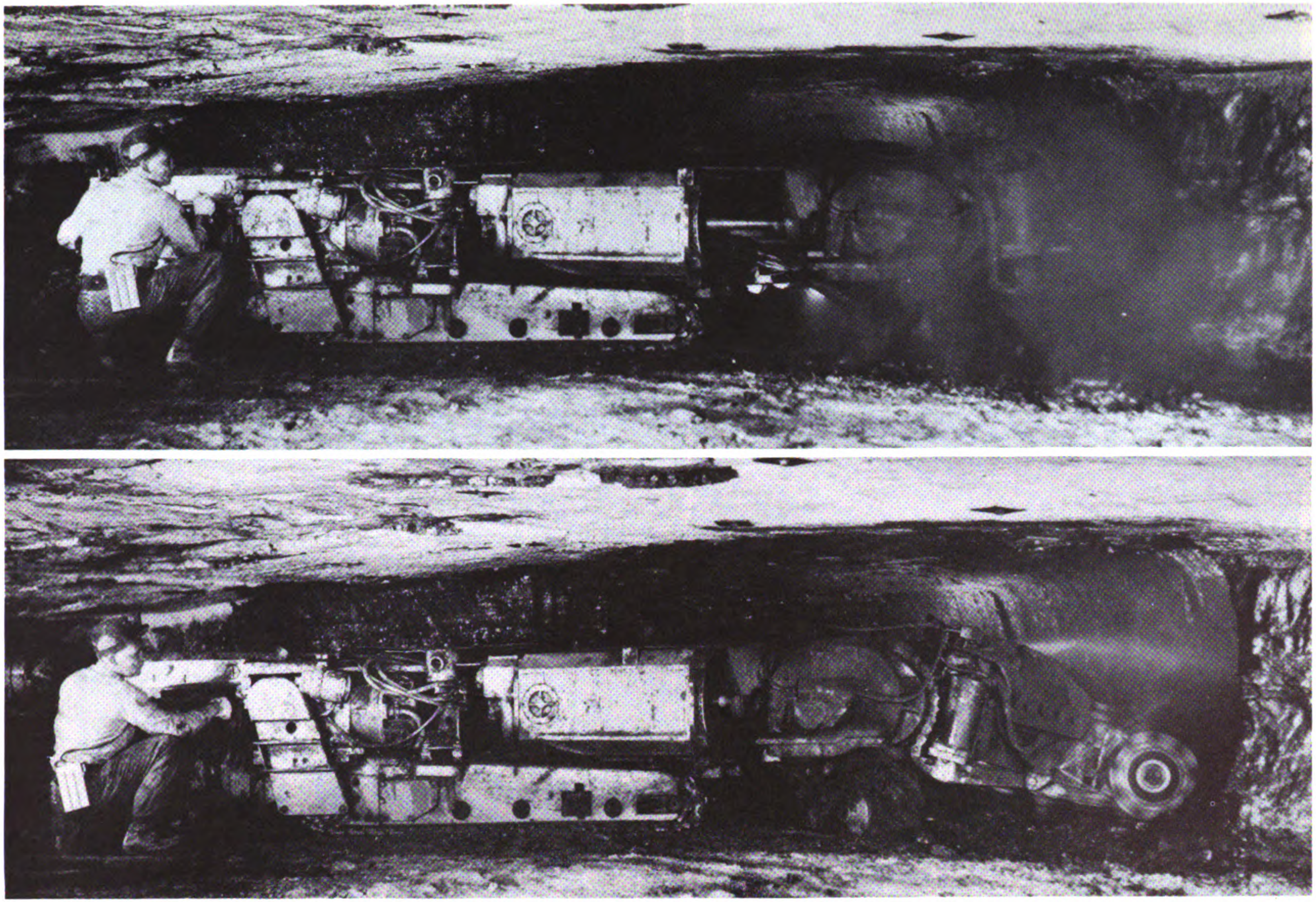

Figure 4. - Before and after photographs show effects of controlling dust in mines. Upper—Without dust control, continuous-type mining machine starting room neck begins raising cloud of dust. Lower—Water sprays allay dust at moment of formation, improving visibility and safety.

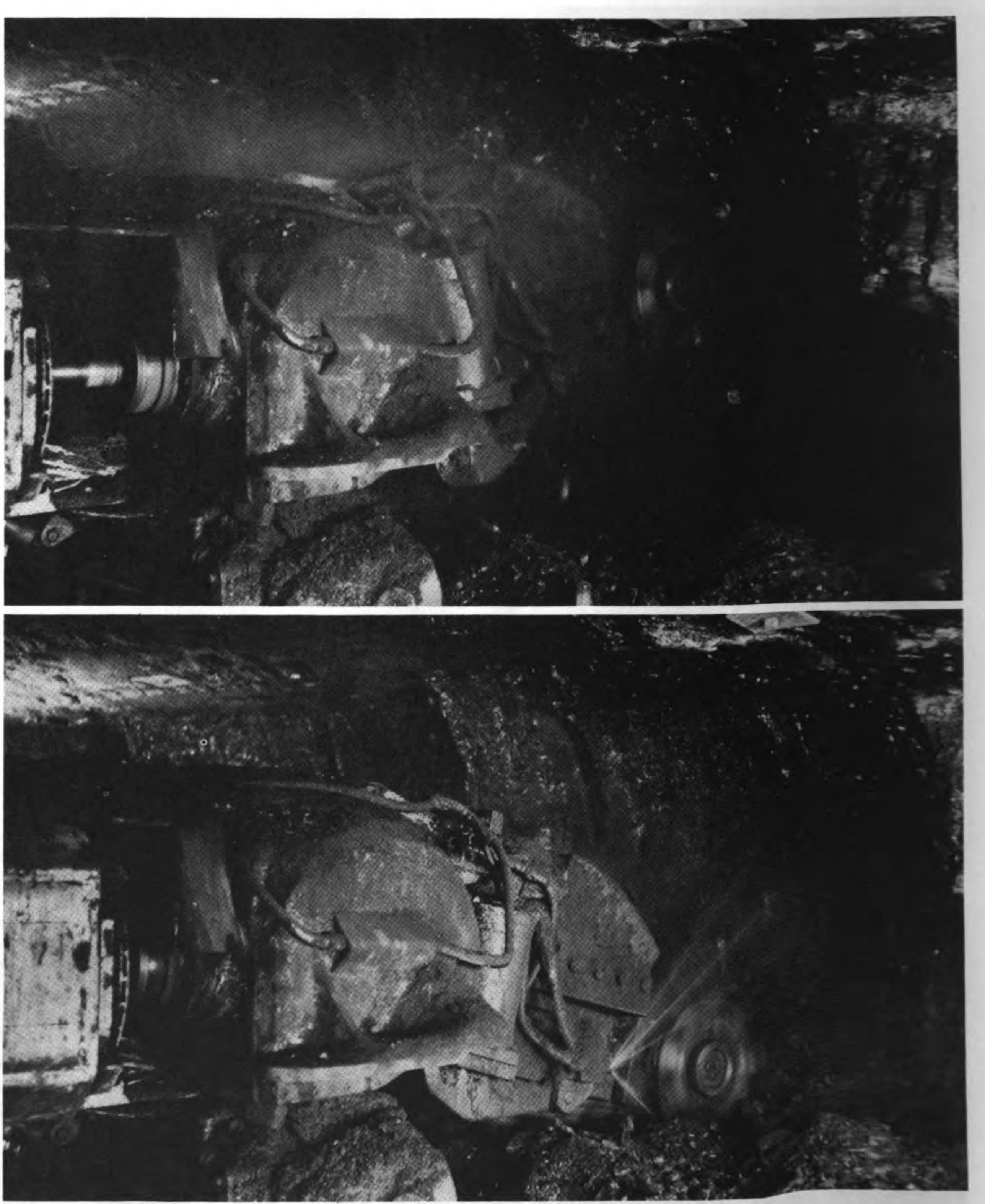

Figure 5. - Upper—Spray-equipped continuous-mining machine starts cut without spray operating. Lower—Spray in operation. Note clearness of face and how water strikes coal, sending sprays in all directions.

so that much less dust is generated. Then, too, the air at this point is recirculated, decreasing the tendency for it to spread into the general atmosphere. Thus sprays - prefereably high pressure (300 to 600 p.s.i.) - are universally employed by users of continuous mining machines.

Although it is difficult to eliminate the fine dust from the air with water sprays, even in scrubbers, it can be trapped at the point where it becomes airborne if suitable sprays are used. There is an optimum size of liquid droplets for wetting dust, and this may be of the order of 50 to 100 microns. In controlling dust on the continuous-type mining machines it will be necessary to wet the dust as it leaves the broken coal.

A new-type continuous mining machine has been reported in use in Pennsylvania. It undercuts and shears on both sides simultaneously. Electrically operated hammers mounted on a telescopic carriage vibrate against the coal face. Water spurts from nozzles in the cutter bars and settles dust as the kerf is cut. A water spray on each side of the machine lays the dust created by the vibrating hammers (12, 41).

During 1954 continuous-type mining machines were operated in 82 coal mines in the United States (1). Wetting was used in all mines, and in addition ventilation was used to a large extent to help control dust. Of the 82 mines 63 employed 100 or more men, and all used wet methods of dust control. One mine with less than 15 men also mined coal with a continuous mining machine.

Blasting

Blasting has always been the source of large volumes of smoke and dust, and the increased number of coal mines in which blasting is done on shift presents a new problem. In States where on-shift blasting with explosives is prohibited, blasting in coal mines is done with permissible compressed gas or air devices. The Bureau of Mines made a limited study to determine if their use resulted in the formation of less dust. So far as could be determined there was no appreciable difference (53). In some mines the hole is filled with water before the shell is inserted. From visual observations some mining men believe that this results in less dust. It is believed that water with a wetting agent in it should be tried. If there were any cracks or crevices in the coal, the wetting agent would tend to cause the water to penetrate farther and thereby reduce dust formation. Certainly it would wet the loose dust in the drill hole more thoroughly.

Although wetting of all surfaces at the face of a working place before blasting has been recommended for a number of years, relatively few coal mines have adopted this practice. Recently gas was ignited at a face in a coal mine. It was believed that the explosion was restricted to this face because rock dust had been applied within a short distance of the face and the remaining distance was wetted down before blasting.

Control of dust during and after blasting consists of operating fog guns during blasting and application of water before and after blasting. During 1954 a few coal mines in the State of Washington used fog guns or "bazookas" while firing shots, and it was reported that they allayed the dust (1). Control measures were very limited, except for ventilation, and out of 3,413 coal mines throughout the United States the coal pile and surrounding surfaces were wetted in only 155 mines, and over half of these were mines in which more than 100 men were employed. Blasting was done off shift in 231 of the mines.

Transportation

Improvements in operating ideas for controlling dust often are made by the mechanics and engineers at the mines. Phillips (10) at a coal mine in Kentucky eliminated solenoids and other electrical parts, reduced the cost from about $80 to $12, and removed a constant source of trouble by constructing a direct-action lever to control sprays on belts. A quick-acting, 1/2-inch valve was installed under the center of the belt about 10 feet from the discharge. Attached to the valve was a lever that had a roller on the free end. The roller contacts the belt in such a manner that, when loaded, the belt depresses the lever and opens the valve, which allows water to flow through a pipe and a spray to moisten the coal on the belt. When the belt is empty, it rises, allowing the roller and arm to rise by direct action of a spring; this shuts off the water.

Transfer and discharge points are dusty locations in mines, yet dust control at such locations was not a general practice, as only 20 percent of the coal mines used controls in 1953 and 1954 and visible dust was reported at nearly half of these installations (1). The tops of loaded cars were wetted before or during transportation in less than 3 percent of the coal mines. Where shuttle cars haul the coal from the face to a loading ramp, considerable dust can be thrown into suspension, particularly at the loading ramp. In mines using shuttle cars only about 1 in 5 applied water on the coal during dumping. Water was used on conveyors during transportation in 7.2 percent of the mines and at transfer and discharge points on conveyors in 27 percent of the mines.

Dust was allayed on haulage roads in only 92 mines in the United States and on sidetracks in 62 mines. Chemicals were used to consolidate the road dust on main haulage roads in 36 mines and on shuttle car haulage roads in 99 mines.

Preparation and Processing

The problem of controlling coal dust in a power house (46) was solved by adding a wetting agent to the feed water and the solution was then sprayed on the coal. The water and the wetting agent were mixed in a tank and were pumped from there to three sets of sprays. When the solution was not needed the liquid passed through a relief valve and was then returned to the tank. A float-operated valve maintained the desired level of the liquid in the tank. The float dropped as liquid was used, causing replacement water to pass through an eductor proportioner to the tank; the eductor drew the wetting agent from a barrel and provided the proper mixtures of water and wetting agent. The solution going to the sprays passed through two solenoid valves, which opened and closed on an impulse from a feeder-belt-operated microswitch. The weight of the coal depressed the microswitch, causing the valves to open. When no coal was on the belt, the valves remained closed. One part of wetting agent was added to 700 parts of water; the wetting agent cost only 0.2 percent of the price of the coal. The weight of water added was only 1 percent of the weight of the coal as unloaded.

Essentially the same method of control is used at a powerplant (44) on a coal-car dumper. A wetting agent is added to city water in the proportion of 1:100. About 40 gallons is used on each car. A set of 30 nozzles, 12 inches on centers, is placed on the upper header that rotates the car. These nozzles spray the solution on the car as it rotates through the first 90°. The lower and stationary header over the coal pit contains a set of 44 nozzles on the same centers. As the car starts the second segment of rotation, these lower nozzles begin to spray over the pit and remain on until the car passes the 90° point as it returns to its normal position. The pump is started manually, but the sprays are controlled by two solenoid valves.

Control of coal dust at tipples and cleaning plants can be effective, and in some plants such control is being exercised. In a discussion of this subject Bearce (2) describes practices that are used. Where dry coal is dumped, water sprays are used to knock the dust from the air; however, in dry methods the dumping area is enclosed as completely as possible, and the dust is exhausted by a fan. At the feeders water sprays are used, and they are turned on and off with the feeder. At an Ohio plant the 3/8-inch by 0 coal cannot be wet, and the coal stream is enclosed and kept under negative pressure. Belt conveyors throw dust into the air at the loading point, the discharge point, and the idlers on the return run. Very dry coal also throws up dust as it passes over each troughing idler. This dust is controlled by providing skirt boards and close-fitting wearing strips on the carrying side of the belt. These belts are then covered and kept under negative pressure. The belts are vented only at the loading and discharge points. No effective way has been found for collecting the dust from the underside of belts for the dry method; however, use of a conventional scraper under the head pulley and placing a wet pan under the belt provide control. Water sprays are used to wet the dust in the drag conveyors. If a dry system is used, these conveyors can be covered and vented. Dust on screens can be allayed with sprays; or, where the screening is done dry, the screen itself can be made nearly dusttight and the enclosure kept under negative pressure. At 1 plant the bins are enclosed and vented with an exhaust of 10,000 c.f.m. At the same plant dust from the three crushers is controlled by enclosing the discharge chutes and providing a vent pipe handling several thousand cubic feet of air a minute. This eliminates any dust emission from the crushers.

The driers are usually kept under negative pressure by the fan circulating the drying air, and they do not present the problem of emitting the dust into the air of the plant; however, the dust from the coarse-coal driers is exhausted into the atmosphere where it is deposited outside the plant. The dust from the fine-coal driers is collected by cyclones that are not designed to collect the very fine dust. The exhaust from the cyclones is collected by a cyclonic scrubber, which consists of a cylinder through which the dust-laden air passes, having entered at one end tangentially to give it a whirling motion. A spray or sprays on the axis of the cylinder atomize the water that engages the dust particles. Centrifugal force carries the water and dust to the wall of the cylinder, while the cleaned air leaves the open end opposite the inlet. The same device is used to clean air from the other enclosed areas of the plant.

Use of Water

Water is not used extensively to allay dust on haulageroads in coal mines. There are two reasons for this. In the first place, in many mines (especially in larger mines) the roadways are kept clean, and the well-maintained track and solid car bodies do not allow much dust to be deposited on the roadbeds. Most of the men are hauled in man-trips and therefore are not exposed for long periods to dust from the roadway. In 1 State only 7 out of nearly 700 mines used water on the haulageroads. In an adjacent State water was used on the haulageroads in about 20 out of 40 mines. In another State water was used on roadways in only 1 out of nearly 400 mines.

The second reason is that roadways are rock-dusted, and some coal-mine operators do not believe it is good practice to wet this dust, because in case of an explosion, it might not be raised into suspension if wet. Although this is sound reasoning, the fact is that coal dust on top of rock dust can explode, even if there is enough rock dust below it to render the mixture inert to explosibility. If this dust is consolidated by sprinkling, the coal dust could be wetted, and it would not be raised into suspension. In sprinkling, the water should not be applied with such force as to raise dust into the air (31).

Wetting Agents

Wetting agents are not used extensively to aid in allaying dust underground in mines, but they are used on tipples at coal mines. They have a definite application in coal-cleaning plants and at coal-dumping points on docks.

Not all wetting agents are suited to wetting all kinds of dust. Each wetting agent is developed to meet certain conditions, and those conditions are generally dictated by the market demand for certain types of wetting agents. Some of the surface-active agents work well in hot but not in cold water; others are active in soft but not in hard water; still others have odors that are objectionable in mines. It has been found from experience that each mine is a problem in itself and that few, if any, wetting agents will be entirely satisfactory; rather, the commercial product must be modified by mixing one wetting agent with other suitable chemicals. The selection of proper wetting agents, as studied by the Pennsylvania State University, has been reported by Charmbury and Mitchell (7). Tests were conducted on 0.2-percent solutions of various reagents in distilled water into which particles of coal dust were dropped. Those that sank within 30 seconds were tested further in acid and basic water in a pH range of 3.0 to 11.0. Those reagents that were found satisfactory were tested still further in solutions containing salts likely to be found in mine water. Those that were satisfactory were then tested in lower concentrations. Of 144 reagents, 67 were satisfactory in a concentration of 0.2 percent in distilled water for wetting a particular bituminous coal. Only 26 were satisfactory in both acid and basic waters and in the presence of all salts tested. The minimum satisfactory concentrations ranged from 0.003 to 0.2 percent.

Consolidating Dust Deposits

In areas where self-propelled cars are used movement of cars raises dust into suspension. In a few mines water is used to allay the dust and to consolidate the roadway. In some mines water affects the floor material adversely and causes chuckholes into which the wheels fall and may stall the "buggy." To overcome this condition calcium chloride is distributed along the floor. When properly applied, this chemical allays the dust and forms a fairly hard plastic surface. For every mine that uses only water on haulage roads calcium chloride is used in 3 or 4 mines. Even so, this is only a small percentage of those mines in which self-propelled cars are used.

Maintaining a roadway where trackless equipment is used is a problem, but according to Christner (9) a drag attached to a shuttle car can be of real advantage. The drag is a piece of 30- to 40-pound rail slightly shorter than the width of the car. It is hung by loops of wire under the car midway between the front and rear wheels so that the flange of the rail is slightly shorter than the bottom of the tires. This device maintains new or reconditioned roads in good condition but will not help old, rutted roads.

Ventilation

Tests were made to compare two exhaust systems for face ventilation in a coal mine. With an auxiliary fan the dust concentration was reduced about 70 percent, but the dust concentrations were still too high. The exhausted air and dust were discharged into return air where no men were working, so that the dust was not breathed by workmen. Rock dust was also dispersed through the fan as needed. The system was capable of reducing the dust on one side of the continuous-type mining machine, but all or a large part of the dust from the machine and the two roof drills mounted on the machine was carried to the breathing zone of the other driller.

Providing ventilation at the face of working places in coal mines where continuous-type mining machines are in operation has proved to be a definite problem. The dust concentrations often greatly exceed recommended limits of dustiness (33), and large volumes of air are needed to reduce the particle count below an acceptable limit. In a coal mine (20) it was found that well-constructed line brattice would provide fair ventilation for 100 feet, but beyond that point the volume of air decreased rapidly. In an effort to solve the problem an exhaust auxiliary fan and 2-foot-diameter tubing were used to draw the air over the machine and from the face, entraining the dust and carrying it to the return airway. Measurement showed that the fan would pull 4,000 to 4,500 c.f.m. of air through 200 to 280 feet of tubing. The water gage varied from 2.3 to 2.7 inches of water. Although this method provided more air at the face, it is apparent that further steps must be taken to allay the dust. Large volumes of air can be maintained at the end of line brattice, and Strachura (51) reports that in a coal mine in Indiana 10,000 c.f.m. of air is maintained at the end of line brattices where high methane content is found at the coal face. In a large coal mine where a continuous-type mining machine was operated the air velocities ranged from 2,300 to 11,000 c.f.m. at the end of the intake line brattice. The dust concentrations ranged from 2 million particles per cu. ft. in 11,000 c.f.m., to 14 million particles per cu. ft. in 2,300 c.f.m. of air. The cause of the higher concentrations could not be determined, but undoubtedly the dust was from regular mining operations upstream. It is evident that the ventilation must be maintained at a high volume to offset ineffective allaying of dust in some coal-mine operations. It also points to the need of more studies of dust-control methods for mining practices in coal mines.

METAL AND NONCOAL MINING

Working Methods

The present trend in some large companies is toward introduction of industrial hygiene departments. The benefit of these departments is beginning to be realized both in effective dust control and in savings in money by purchasing equipment that is suitable, based on prior planning. The advantages and effectiveness of a dust-control department are described by Knudsen (34).

In 1947 a copper-mining company organized an industrial hygiene department, the function of which is to recognize hazards and provide adequate protection at such locations. Plant surveys or management suggestions may indicate need of ventilation or air conditioning. Drawings are made showing sizes and types of hoods, ducts, and related equipment. Before new ventilation projects are begun or old systems are revised, a thorough survey is made of all conditions. Weighted average exposures are determined where possible, and ventilation is provided on the basis of maximum allowable concentrations. When it became necessary to build a new and larger crushing plant, dust samples collected from rafters in the old crushing plant were analyzed and sent to dust-collector manufacturers, who determined the settling rate, the particle size, and the collector efficiency ratings. As the schist-type ores could not be wetted, spray systems were ruled out, and an exhaust air system had to be used. Empirical formulas developed in previous research were a start in solving the problem, but they had to be followed by a more practical plant operations approach. Because of liability of tampering with dampers, regulated pipe sizes were employed instead, except for the sample mill exhaust system, where it was more advantageous to use diversified control. Wherever possible, hoods were designed with entering velocities of less than 500 f.p.m. Branch-duct velocities were about 2,500 c.f.m.

A carbon company plans to work a new diatomite deposit by a new type of operation, which, it is claimed, will raise no dust (8), make no noise, and be completely hidden from residents in the locality. The method of working is a trenching or borrow-pit system consisting of trenching the earth, extracting the diatomite ore, and refilling the trench behind the operation. The deposit is in a hill, roughly circular, consisting of overburden overlying banded alternate deposits of diatomite and overburden. The entire hill will be encircled with shrubbery and trees before the operation is begun. The first operating phase will be to start at one edge and excavate a segment to reach the bottom limit of the diatomite deposit. This will be the bottom of the borrow pit. This will be followed by quarrying and backfilling.

Increasing interest is being shown in longhole drilling in metal mines because usually greater efficiency and lower cost result from drilling of this type. Some tests of the method indicate that higher water pressures are desirable to remove the chips and the dust from the hole. This may necessitate the use of larger holes in the drill steel. One western mine (14) has water swivels of local design that are said to introduce enough water at 75 to 80 p.s.i. to clean the cuttings from the holes. Holes 67 feet long have been driven without difficulty, attributed to better drilling technique and to the new design of water swivel.

A new departure from standard mining practices has been made by two New Mexico potash-mining companies (3). Mining and loading are now being done by continuous-type machines. Commercial types are used in both mines; and, in addition, in one mine a machine constructed in the company shops is in operation. Control of dust is a difficult problem, as the sylvite ore is readily soluble in water. The type of machine is such that dust collectors cannot be used. Ventilation is the only recourse available to them at present.

Preparing Ores and Other Minerals

In 1953 preparation plants in the United States were receiving more and more attention in efforts to control dust there. In some localities the dust-nuisance problem became more pronounced, and injunctions were obtained. The health of workers in and around plants was given more thought than in previous years, and in some plants the value of recovered product was an additional incentive for collecting dust.

The effectiveness or the lack of dust-control measures in noncoal plants or parts of plants is shown in table 1. Dust samples were collected by Bureau of Mines personnel at the request of management, who thereby showed concern for health conditions in their plants. As can be seen from the dust counts, some operators are unfamiliar with dust hazards, whereas others show knowledge of them and have taken measures to allay or collect the dust. For example, consider two perlite plants. Plant A keeps the buildings clean, removing dust from the floors and rafters. The

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dust at the primary crusher was 15.3 million particles per cu. ft.. but in all other places sampled the concentration was less than 5 million particles per cu. ft. An exhaust-air system was installed, and dust was well-controlled. In plant B an effort was made to control the dust; but the system was ineffective, and there were high concentrations of dust throughout the plant.

One of the dusty points in crushing plants is where the rock or ore is dumped into the primary crusher (38). When the tops of loaded trucks are sprayed before dumping, the dust often is allayed during dumping. Plants H and I illustrate this difference, although sprays were not used. In plant H the rock was wet from weather conditions and showed 2.1 million particles per cu. ft., whereas the rock in plant I was not wetted, as melted snow and rain had wet the rock in the quarry, but it had dried enough to give a count of 34.2 million particles per cu. ft. A spray had been provided to wet the top of loaded trucks, but it was not used because the rock was considered wet.

TABLE 1. - Dustiness of work places in preparation plants in million particles per cubic foot

Product	Plant A, perlite	Plant B, perlite	Plant C, sand-gravel	Plant D, lime	Plant E, lime	Plant F, lime	Plant G, brick	Plant H, rock	Plant I, rock
Primary crusher ..	15.3		8.3		41.2		11.3	2.1	34.2
Screens	4.8	614.0					32.0		
Conveyor								8.1	
Secondary crusher.		110.0					22.8	10.5	12.0
Conveyor					11.5		1.0		
Screens		135.0					5.4	2.0	5.1
Bins		125.0				30.9			
Stockpile		213.8							
Feed furnace	4.7		7.1			(112.6			
Bagger	1.3			2.1	22.3	(12.4			
Tunnel		592.4	59.7			(22.9			
Drier			.9						
Hydrator				32.3	9.1	1.3			
Kiln				3.1		1.9	12.6		
Yard	.9	35.5				6.8	2.2		
Free silica[1]		1-6				2			

Dust control:

Plant A:	Plant cleaned dust from rafters, blower fan units enclosed, 2 cyclones, centrifugal fan.
Plant B:	111 to 781 million particles per cu. ft. near plant, 2 exhaust units at crushers, Multiclone collectors, fine dust blown outside, respirators.
Plant C:	Material wash-trommeled and stockpiled, thence to drier and heater.
Plant D:	Exhaust fans, dust on floors of buildings.
Plant E:	Dust on floors and rafters.
Plant H:	Samples affected by weather and moisture content of rock; rock was damp.
Plant I:	Sprays for top of loaded trucks not used. Sprays with wetting agent below primary crusher, under secondary crushers, on conveyors, under screens; discharge into bins.

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[1] In percent.

In lime plants dumping points are dusty, and it is also dusty at the crushers. Bagging and handling dust in railroad cars are likewise dusty operations. In plant F, inside a railroad car where processed lime was being loaded, the dust concentration was 31 million particles per cu. ft. The processed lime is generally dustier than unprocessed lime; 112.6 million particles per cu. ft. was in suspension at the process bagger where minus-100-mesh lime was handled.

The favorable results obtained by careful planning in a large plant have been detailed by Knudsen (34). At one plant eight enclosure systems are operated. System 1 encloses the pan feeder and the jaw-crusher feed, requiring 30,000 cubic feet of air per minute. System 2, enclosing the No. 1 conveyor point, uses 20,000 c.f.m. of air. The secondary-crusher-plant exhaust system requires 97,100 c.f.m., divided essentially equally (22,000 to 30,000 c.f.m.) into 4 sections. The sample mill is on a separate system and requires 12,000 c.f.m. For 7 of these 8 systems, the total power required is 287.4 hp. The effectiveness of this system is attested to by the overall low-order dustiness in the plant: In the primary crushing plant the dust concentrations range from 0.8 to 6.4 million particles per cu. ft. The mean concentration is of the order of 3 million particles per cu. ft. In the secondary crushing plants the concentrations vary from 1.1 to 7.2 million particles per cu. ft., the mean being about 3 million particles per cu. ft. In the sample mill the concentrations averaged 1.5, 1.2, and 0.8 million particles per cu. ft. on the ground floor, on the sample cutter floor, and in the junction house, respectively.

Wet-type inertial separators were used on the first 4 systems installed, but as water was scarce the last 3 systems in the secondary crushing plants were equipped with dry-type inertials.

The various types of collectors, although essentially the same as in recent years, are being refined, and a better conception of their modification, combination, and application has developed. An electrostatic precipitator was being used in at least one metal mine, and the concept of its application has been broadened to include it in combination with an impinging-type collector. The dust that passes the impinger collector is passed to the electrostatic precipitator which collects most of the remaining dust.

Ventilation

Opening of numerous small uranium mines has created a problem of the health of the miners. Utah uranium mines are generally small, and the ventilation is also often inadequate. In a survey of 75 mines Morrill (43) found that in some mines air was being forced down 8-inch churn-drill holes, but the air was not reaching the working areas effectively. A few mines were using churn-drill holes as substitutes for ventilation raises, but most of these mines had not established any ventilation raises to provide effective aircourses. To correct these conditions, mechanical ventilation is necessary, and it is advisable to place the mine under positive pressure. Ventilation rates for control of radon and radioactive dust suggested by Holaday and Ayer (43), United States Public Health Service, are: For concentrations up to 10,000 micromicrocuries per liter of air, at least 500 c.f.m. should be applied to the working face of each drift and 1,000 c.f.m. to larger rooms or stopes. For concentrations above 10,000 micromicrocuries per liter of air the amount of air supplied to the working face of each drift should be at least 1,000 c.f.m. and 2,000 c.f.m. for each larger room or stope. Natural ventilation should not be relied upon to remove contaminants from the working atmosphere. The mines should be laid out to provide for effective aircourses throughout the underground openings; and, if possible, the surface openings should be at different elevations from the main inlet. The ventilation system should operate for at least 30 minutes before the miners enter the mine.

TUNNELING

Working Methods

When plans were made for driving a tunnel as part of the West Virginia Turnpike, the contract provided for observance of certain health and safety provisions (55). It specified that the concentration of free silica dust in the tunnel atmosphere should not exceed 5 million particles per cu. ft. of air. It also required wet drilling and continuous wetting down of the muckpile during mucking. A ventilation plant with a capacity of 20,000 c.f.m. was required. This system was operated continuously during the 6 workdays each week and for at least 2 hours before resumption of work on Monday morning. A preemployment physical examination was required, and those who had silicosis or a pulmonary condition that might be aggravated by environmental conditions were not employed. The rock was primarily sandstone with a high free-silica content.

Samples were taken once a week for dust counting and analysis for free silica, carbon monoxide, oxides of nitrogen, and aldehydes. Samples were collected occasionally for the other gases. Dust samples were taken in the breathing zone of the workmen with a Staplex sampler fitted with a pleated filter. Whereas the free silica in the rock was about 54 percent, that in the air during mucking ranged from 25 to 37 percent, the average being about 31 percent. The same average was found during drilling. The results of dust sampling are discussed later under the appropriate headings. The recommendation that contract provisions covering health and welfare should be spelled out in detail is one that should be observed in driving all tunnels.

Drilling

The West Virginia Turnpike tunnel (55) was drilled from a conventional jumbo, on which were mounted 13 drifter-type pneumatic-type drills at 4 levels. Each drill required about 1/2 g.p.m. of water, and the water controlled the dust effectively, as the counts ranged from 1 to 6 million particles per cu. ft. of air and averaged about 3 million particles. As the free-silica content of this dust averaged 31 percent, the count was well within permissible limits and those specified in the contract.

In twin tunnels with a cross section of about 20 by 20 feet, wet drilling[7] was done from a jumbo with 3 drills mounted on the deck and 3 near the floor. Samples collected on the floor of the tunnel at one location and at the breathing level of the drillers averaged 1 million particles per cu. ft. and at a second location, 2 million particles per cu. ft. On the deck of these jumbos, the concentrations ranged from 1 to 5 million particles per cu. ft. The higher counts were toward the end of the drilling period, and the concentration was slightly higher on the right than on the left side of the jumbo. The tunnel was also being reamed near its outer end. The jumbo there had 2 decks with 4 drills on the top deck, 3 on the middle deck, and 2 near the floor of the tunnel. Before drilling was begun the air contained 1 million particles per cu. ft. During drilling the dust concentration on the floor and on the middle deck was 1 million particles per cu. ft., and on the top deck it averaged 1 million particles per cu. ft.

Water was ample in volume and pressure, being regulated with a valve by each driller. The drills had New York-type waterheads. The rock was greenstone, containing about 15 percent of free silica. This operation is typical of good dust-control practices.

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[7] Owings, C. W., unpublished data.

Loading Rock

Loading and unloading rock can be dusty, but the dust can be controlled adequately, even with unusually dusty operations. In tunneling, the material is wetted before and, at times, during loading. Some tests[8] were made in a tunnel where the muckpile was wetted thoroughly before loading was begun and then during loading, as needed. The dust concentration ranged from 2 to 11 million particles per cu. ft., and the average of 10 impinger samples was 5 million particles per cu. ft. This represented 3 loading cycles and a total of 2 hours and 20 minutes loading time. The high count was at the end of the loading cycle, and the teeth of the bucket scraped into the face of the tunnel exposing the dry face. The dust raised by blasting had not settled completely when mucking was begun, and the air during the loading operations was less dusty than at the start. At 1 face 20 minutes after blasting the dust concentration was 9 million particles per cu. ft., but the loading operations immediately afterward raised only 2 and 5 million particles per cu. ft. In another place, 35 minutes after blasting the air contained 7 million particles per cu. ft., but during loading the concentrations were only 3 and 4 million particles per cu. ft. In each of the 3 places, as the loading progressed, the air became more dusty; during the first 20 minutes the dust concentrations were 5, 2, and 3 million particles per cu. ft., respectively, whereas the last sample in each place was 11, 5, and 4 million particles per cu. ft., respectively. The free-silica content of the rock was about 15 percent, and the maximum allowable concentration would have been about 20 million particles per cu. ft., but actually the average exposure was 5 million particles per cu. ft. In tunneling, then, even in high-free-silica rock, it should not be difficult to maintain a healthful atmosphere.

Mucking in the West Virginia tunnel (55) was begun about one-half hour after blasting and after the foremen had inspected the tunnel. A bulldozer was used to clean up the rock thrown back from the heading by the blast, and a 2-cubic yard diesel shovel loaded the muck into diesel-powered Tournarockers for removal from the tunnel. Samples of airborne dust were collected at four locations during mucking, at the heading just ahead of the shovel, just behind the shovel, on the bottom near the jumbo, and on top of the jumbo. The jumbo was about 125 feet from the actual mucking operations. There was little difference in dust concentrations at the four sampling locations. The lowest dust count was 8 million particles per cu. ft., and the highest count was 32 million particles per cu. ft. The high count of 32 million particles per cu. ft. occurred when insufficient water was being applied to the muckpile. Normally the dust counts ranged from 8 to 17 million particles per cu. ft. The free-silica content of the airborne dust averaged 31 percent.

QUARRIES

Drilling

Dust from drilling in quarries is not considered hazardous under normal conditions. Deep holes are drilled with churn drills in most quarries or with wagon drills. Water is used in these holes and little, if any, visible dust can be detected. Occasionally, conditions are such that wet drilling is not possible and then other dust-suppressive measures must be provided.

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[8] See footnote 7.

In a quarry, rock containing 30 percent quartz was being drilled with wagon drills and jackhammers. It had a number of crevices and seams in it; hence, when water was used in the holes, it ran away from the bits and out through the seams, causing the remaining wet material to clog the hole.[9] This made the bits stick, and in loosening the steel the bit inserts frequently were lost. The bits were 2-1/4-inch wedge type, with tungsten carbide inserts. The loss of the bits so increased the cost that drilling was done dry, which caused large volumes of dust to fill the air around the drillers. To overcome this condition, several two-liquid nozzles were built at the quarry machine shop; by mixing the water and compressed air and regulating the air pressure until a suitable spray pattern was formed, the dust was controlled. As first constructed the nozzle reduced the dustiness of the air to a safe limit of 4.5 million particles per cu. ft. of air, and after further adjustments the concentration of dust was only 0.8 million particles per cu. ft. of air. It was found that when the spray was directed at the drill steel, the dust formed a mud cake that caused the drill steel to stick in the hole. When the spray was directed to one side of the hole and opposed to the direction of the wind, the dust concentration was maintained well below 5 million particles per cu. ft. of air.

Transportation

Dust can be prevented during transportation or dumping, at least in part, by spraying the loaded material at the start of or during transportation. In quarries, when the rock is considered wet (such as after a heavy rain or snow) the tops of the loaded trucks are not wetted; but, when considered dry, water is sprayed on top of the rock from an overhead source. This often consists of a pipe with about 1/8-inch holes drilled in it. The truck passes under the spray, which is turned on only long enough to wet the top material. It has been observed that often when the rock is considered wet, only the top of the loose material is wet before it is loaded in the quarry; below the surface the rock often is dry.

Quarries or opencut mines at times have a definite dust problem on the roadways, especially where the climate is dry. One such mine maintains 26 miles of roadway. Three crews of men are kept busy all the time sprinkling the dust with water from carts or trucks. The use of chemicals or wetting agents require careful consideration, as they may affect flotation.

In quarries dumping rock in the open often is not considered a hazard; but it can become so, particularly if the rock is dry and the wind blows the dust over workmen. When the rock is considered damp, as after a heavy rain, dust may be below maximum allowable concentrations, but if the free-silica content is high, even seemingly clear air may be hazardous. In tests made in a quarry containing high-silica rock[10] the average dust concentration was 5 million particles per cu. ft. Several days previously, rain of cloudburst proportions had fallen, and the rock, especially the fines, was damp. Clearly, when the fines dried, there would be a definite hazard.

In another quarry after an 8-inch snowfall, followed by a heavy rain, the rock looked damp, but where it was dumped at the primary crusher the dust ranged from 27 to 47 million particles per cu. ft. and averaged 34 million particles per cu. ft. The rock was dumped very slowly.[11] If all the load had been dumped at one time, the amount of dust in suspension undoubtedly would have been much higher.

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[9] See footnote 7.
[10] See footnote 7.
[11] See footnote 7.

REMOVAL OF AIRBORNE DUST

Dust Extraction and Filtration

The International Labor Office at Geneva (31) recommends that: All airborne dust should be arrested as speedily and completely as possible by suitable methods; when wet methods are used, the water should cause the dust to impinge on a surface on which it may adhere; when dry methods are used, the dust should be filtered or precipitated; filters should also have a particularly high efficiency in the size range below 5 microns in diameter; and the filtering devices should be checked periodically. Research in the United States has been directed along these lines during the past year.

An electric company studied several air-cleaning and sampling mediums at face velocities of 0.5 to 250 cm. per sec. (23). Membrane filters were used to test them, and they were examined under both the optical and electron microscopes. The collection efficiency was expressed both as particle size and as face velocity. As a result of the tests it was concluded that the efficiencies varied on the filter medium tested with particle size, with face velocity, and with the medium.

The methods for evaluating the efficiency of dust collectors used by one manufacturer applying to one particular aerodyne collector are presented by Eiserman and Prout (19), who claim that the basic principles involved would apply to any mechanical collector.

The inertial separator is probably one of the oldest types of dust collectors. The basic principle is the terminal velocity of the particle, which is governed by its size, shape, distribution, surface area, and specific gravity. Improvements consist of changes in design of the equipment. In recent years small multiple units have been used, and the smallest practical radius has been about 1-1/2 to 2 inches (50), although a recent development for removing solids from water has utilized 0.4- to 0.6-inch units in nest arrangements. At the Harvard Air Cleaning Laboratory it was found that the 2-inch units will remove completely all particles above 8 microns in size (50) and approximately half of those in the 2-micron size range, depending on the specific gravity of the material involved.

A new device of novel design is a small-radius cyclone. It has a well-shaped bell-mouth entry and a decreasing radius separating cone. Its performance (50) compares with that of other small-radius cyclones. Another development is a strip-type unit, which consists of a series of flat, extruded strips with semicircular ends that form small cyclonic sections for separation. The strips are placed in a vertical position with staggered rows. The bottom of the strips leads to collection hoppers. Collection of fly ash has been reported to be as high as 80 percent by weight when 12 rows were used. For cement dust 80 to 81.6 percent weight recovery was obtained on a dust with 38 percent of the particles less than 1 micron in diameter.

The greatest development in filtration has undoubtedly been in filter mediums. Developments in the glass fibers have been outstanding. Very fine glass fibers (1/2 to 1 micron) have been produced commercially in the past 2 years. All-glass paper or webs have been produced (50) that have performance characteristics exceeding those of the so-called absolute cellulose and asbestos filters. Webs of 1 type in 10 mil thickness (0.010-inch) at a velocity of 5 f.p.m. have an efficiency of 99.98 percent or penetration of 0.02 percent or dioctyl phthalate smoke, which has a mean particle size of 0.3 micron. Fine fibers of aluminum silicate (1 micron and less) have been made into webs that give comparable performance. Fiberglas mats have been made that, though less efficient, have much lower resistance and longer potential life. A unit comprised of this type of glass fiber has been produced to be used in series with coarse-glass fiber filters, which makes ordinary filter banks nearly comparable in efficiency to two-stage low-voltage electrostatic precipatators (50).

At Harvard University Silverman and others (50) have developed a filter utilizing the resiliency and performance of the resin-bonded Figerglas into a variable compression filter. It is arranged to filter radially through a compressed bed of fibers. As resistance increases the compression is relaxed, allowing further penetration of the fibers and increased porosity. On atmospheric dust using 1- to 3-micron (PF 105) glass fibers, efficiencies above 90 percent at 200 f.p.m. filtering velocities have been obtained. They have also studied the coarser mediums (PF 314) arranged in pleated form, and, for dust comparable to atmospheric dusts in size, these mediums will remove approximately 60 to 75 percent by weight and will thus increase the life of the final or "absolute" filters. This filter will show almost 100-percent removal by weight, although it does not do quite as well on the usually encountered atmospheric dust. Recently filter materials made from Dynel and Dacron fibers offer promise in reverse-jet or bag filters for better chemical and temperature resistance than wool.

Results of field tests of wet dust collectors reported by Dennis, First, and Silverman (15) show the operating efficiencies of mechanical centrifugal-type collectors fitted with 20- to 90-p.s.i. water sprays and nonmechanical inertial collectors with water sprays or wetted baffles. The mechanical-centrifugal dust units employed an involute scroll as a precleaner, the scroll deflecting the air through a 270° turn before admission to the separator. In 1 design an 80- to 90-p.s.i. water spray was directed against the impaler, and water sprays were also utilized in the precleaner entry to provide a wetted impingement surface. Another design had precleaner and exhauster scrolls slotted to facilitate sludge removal. Several concurrent water sprays were arranged along the centerline of the precleaner inlet. Flooding nozzles were mounted in the droplet eliminator through which the discharge flows. Several nonmechanical, inertial-type, wet collectors were also investigated.

These tests disclosed some interesting comparisons. Inertial-type collectors showed marked increase in efficiency when provided with water sprays and/or wetted impingement surfaces. Comparisons were made between wet and dry units having essentially the same size, velocity, and separating forces. Previous tests on dry mechanical-centrifugal collectors indicated weight efficiencies from 56.3 to 88 percent. Later data with similar units handling coarse dusts (69- to 145-micron mass median diameter) showed an average efficiency of 84.5 percent and a range of 56.2 to 95.8 percent. Efficiencies for wet mechanical-centrifugal collectors averaged 98.8 percent and ranged from 97.2 to 99.6 percent. It is to be noted that these collectors had precleaner sections that require water-circulating systems. Inertial-type collectors appeared to be nearly as efficient as the mechanical-centrifugal units when applied to similar dusts. These particular inertial collectors rely on fixed impellers to produce an abrupt change in air direction while simultaneously throwing up a water curtain. Against general plant air (1-micron mass median diameter), however, efficiency was 64.5 percent. Various designs of scrubbing towers were 73 to 96.9 percent efficient. These wet-collector tests indicate that overall dust retention is related directly to dust particle size, water consumption, and collector entry velocity but inversely to spray-droplet diameter. High-pressure sprays appear to be more effective than low-pressure sprays or water curtains in overall dust removal. In the field tests uncontrolled variations in operating conditions may result in poor performance, therefore these tests cannot compare to the controlled laboratory tests.

Selection of dust-collecting equipment is becoming more exacting, and the plant or design engineer requires more and detailed information to decide on the type of collector best suited to the needs of the plant and to incorporate such designs in the plans for new construction or remodeling of present facilities. Many sources of information and data are available for this purpose. Lapple (35) has summarized the known types of collection equipment, the type, procurement, and utilization of information necessary for proper selection and design of dust- and mist-collection equipment, and the available reference sources that may be consulted for specific details.

One of the problems confronting those who have to collect dust is disposal of the dust. In some industries the dust is returned to the product, but in others the fine dust must be disposed of - often a difficult problem. In some coal tipples and cleaning plants fine coal dust is mixed in devices similar to pugmills with other wetted fine coal, and then the combined dust and coal is delivered to railroad cars. McAleer (39) also describes the recently developed process of the Impingo filter, which may be of considerable value in the coal industry. In this filter preconditioned granules are made to pass downward at a controlled rate of flow, and the air to be treated passes horizontally through the downward-flowing bed of granules. The dust particles are impinged on the surface of the granules; depending upon conditions, these granules can be disposed of or recirculated. In the coal industry, if the fine dust is not desirable in the finished product, the granules can be mine refuse, and this refuse with the adhering particles of dust can then be sent to the waste dump. On the other hand, if desired, the granules can be coal particles; and they, with the adhering fine particles, can be loaded into the finished product.

In cyclonic scrubbers the most important factor has been the application of high-pressure fog nozzles, and recent studies by Silverman (50) have indicated that the simplest high-pressure fog nozzle operating at a pressure of 400 p.s.i. can recover as high as 70 percent of 0.3-micron, ferrosilicon, electric-furnace fume at constant resistance of only 1 to 2 inches of water. Water-consumption rates of these nozzles are relatively low but require clean or filtered water to minimize plugging and wear. Electrostatic precipitators give the highest performance with the least resistance of all present types of cleaning devices, but their cost has limited their application. In the low-loading field, work has been done by the Harvard Air Cleaning Laboratory (49) on using electrostatic forces at relatively low voltages (10 to 20 kv.). This laboratory has recently completed tests on the Electro-Polar filter which uses a fine Fiberglas medium (PF 136 and PF 105) for separation with a Dust-Stop prefilter. The Fiberglas is placed between two expanded metal screens and a voltage differential of 12 to 15 kv. is placed across the mediums. Tests have indicated that electrifying or polarizing the fibers improves its efficiency on atmospheric dusts and similar aerosols approximately 10 percent, that is, from 85 to 95 percent.

Two types of mechanically charged filters were being studied at Harvard. A static type described by Rossano and Silverman (48) has a bundle of plastic fibers that is charged, and its separation efficiency, resistance, and life are determined for inert and charged aerosols. The other is the continuously friction-charged unit (48) in which mechanical friction charging of fibers at opposite ends of the triboelectric series produces highly charged surfaces. Using a variety of combination of fabrics, it has been possible to generate surface voltages approaching 20 kv. Separation efficiencies have approached 80 percent.

Raising of settled dust is always a source of airborne dust in plants. Vacuum-collecting systems are used to collect this dust from the floor and vertical surfaces in a plant (18). The new cleaning plant at another mine (17) is kept clean with a vacuum-cleaning system consisting of suction pipes that run throughout the plant with outlets located conveniently for hose connections. Dust is removed from the air in the system in a cyclone dust collector and air filters. In still another coal-treating plant every effort is made to keep the dust within the flow of coal, and all dust is filtered through bags. In addition (39), a very extensive vacuum system is provided for picking up any dirt or dust that might not be confined to the dust-collecting system.

AIRBORNE-DUST SAMPLING, MEASURING, AND ANALYSIS

The hazard of airborne dust can be determined only by sampling the contaminated atmosphere and determining the concentration. In dust control either the weight of the airborne dust or the number of particles per cubic foot of air must be determined. In the United States the number concentration is usually determined, because the pathogenic particles are so small that it is difficult to show any marked differences in weight between the harmful minus-5-micron sizes of dust and the larger fractions for short-period sampling.

A critical review of instrumentation and air-sampling methodology has been made by Ingram and Dieringer (30). For particulate matter they discuss sampling from Cohen's method (1897) of ascertaining the weight of solid matter to tests on the cascade impactor by Magill (1949). The conclusions are that, in the broad field of air pollution, few, if any, of the methods of today meet fully the requirements for atmospheric sampling and analysis.

Development of molecular filter membranes has been rapid in the last several years as an outgrowth of development of certain types. The physical properties of MF (membrane filter) material, according to Goetz (25), can provide a means for quantitative separation and rapid concentration of suspended matter, regardless of particle size, so that the aerosols are available for analysis and study. The molecular filter membranes represent dry sets of micellic structure, the elements of which are of molecular order of magnitude and are held permanently without use of binding agents by intermolecular forces. As developed at the California Institute of Technology, these membranes are almost completely wet-dry stable, free from extractable constituents, and with a flow resistivity sufficient to permit filtration of aerosols with sampling rates similar to fibrous filters. The calculated number of pore openings ranges from 10^6 - 10^8 per sq. cm. The flow permeability of membranes for aerosol analysis is about 14 cu. ft. per sq. ft. per min. per in. of water. The membranes are structurally deformed by swelling through contact with alcohols and ethers and are dissolved in methanol, esters, and ketones. The conical shape of the pores, with the smallest openings toward the face restricts the penetration efficiency of the filter and does not necessarily depend on the pore size of the filter. There was virtually no loss in particles during a series of tests.

The molecular filter mediums have an index of refraction of nearly 1.51, and, when immersed in cedarwood or special oils of this index of refraction, the filter becomes transparent to transmitted light, and the deposited material may readily be examined microscopically. Comparative dust counts with the use of membrane filters and the midget impinger indicate that comparable counts may be obtained with the filters with an appreciable saving in time, labor, and equipment, according to First and Silverman (22).

An absolute method of sampling and measuring solid airborne particles by making use of the molecular filter and the electron microscope, as described by Fraser (24), consists of collecting the dust samples on a molecular filter membrane that has virtually 100-percent efficiency, then transferring the particles onto a prepared electron-microscope specimen screen and photographing the particles. The size distribution of the particles is determined by visual measurement from their projection on a screen.The membrane containing the sample is transferred to a prepared Formvar covered screen. Ethyl acetate is poured slowly into a Petri dish until the pieces of molecular filter membrane, which have been cut into small squares, are just wet by capillary action. The Petri dish is covered, and, after the filter material has dissolved slowly by diffusion, the aerosol particles settle on the undissolved Formvar film. An electron micrograph is taken and is projected onto a ruled screen, each 10 cm. of which equals 1 micron. The sizes of the particles are read from the rulings on the screen. It is usually necessary to read 5 to 10 different fields to obtain a sufficient number for analysis. The combination of the high-efficiency filter and the electron microscope is claimed to give an absolute method of sampling and of measuring particles.

The molecular filter has a definite use in sampling where an electric motor can be used, without danger of a gas or dust explosion, and where suitable electric power is available at the point of sampling. It can also be used with a hand pump where grab samples will be satisfactory. It has a limited use in tunnels and in quarries. In coal mines it can be used only with a permissible motor. There is a definite need in coal mines for a high-volume, hand-operated sampler that will trap the ultrafine particles.

Medical research on the causes of pneumoconiosis has shown that the size of particles of airborne dusts plays an important part in this toxicity. To study dusts adequately, a sampler is needed that will divide the dusts collected into particles whose sizes correspond to sizes of dust retained in the lungs. The two sizes naturally are divided into (a) those particle sizes that do not leave the trachea and are removed by coughing and cilliary action and (b) those that correspond to the dusts retained in the alveoli or are phagocyted or dissolved slowly. Such a device has been described by Eisenbud and Harris (26). It has been proposed to use a Design 2 Aerotec Tube to collect samples that would represent dust retained in the upper respiratory area and follow this with a filter that would collect all the remaining dust, which would represent dust entering the lower respiratory area of the lungs.

For determining particle size involving all of the dust particles in a dust-laden atmosphere, a suitable instrument must be used. The thermal precipitator answers this need for certain conditions. The principle of the instrument is based on the fact that hot objects are surrounded by a sharply defined, dust-free zone. Thermal precipitators should collect all the dust if they are properly designed and operated, but the particles are precipitated according to size in the direction of air travel; size measurements therefore must be made across the entire deposit. To overcome this disadvantage several improvements have been made. The rotating thermal precipitator is one of the latest of these improvements. Cember, Hatch, and Watson (5) describe such a precipitator for obtaining a uniformly dispersed dust sample. The instrument has an air channel (1 cm. wide by 0.010 inch deep) milled longitudinally across the center. A nichrome wire 0.010 inch in diameter is held tight by a tension spring in a ceramic insulator, the centerline of the wire being in the bottom of the channel. A 0.005-inch gap is thus provided between the cold collecting plate (glass coverplate) and the hot wire. A 1-r.p.m. synchronous motor drives a rotor. The air sample is drawn through the instrument at the rate of 10 cc. per minute with a water-displacement pump. The temperature of the wire is adjusted so that the dust-free zone surrounding the hot wire is tangent to the collecting plate. As a result of the rotation, a deposit in which the particles are randomly distributed with respect to size is obtained.

The rotating thermal precipitator, although an improvement of the earlier type, has the disadvantage of requiring counting at several points to establish an average count. If the sample strip is counted at 3 or 4 places, a factor can be developed so that only 1 point on the strip need be counted and the factor applied to obtain the correct figure.

To overcome this difficulty, an oscillating thermal precipitator has been developed at the University of Rochester for the Atomic Energy Commission (37) by R. N. Wilson. Using a linear-motion cam in the unit, the collection slide is oscillated during sampling in a direction parallel to the airflow path, thus effectively mixing large and small particles as they are deposited. It has been found to be highly uniform in terms of median particle size and particle number per unit area. The collection efficiency has been evaluated at 99.9+ percent for all particles below 1.0 micron for sampling rates up to 20 cc. per minute. The drive mechanism of the oscillating slides consists of a 1-r.p.m. synchronous clock motor connected to a heart-shaped cam in the control portion of the precipitator. The precipitator is oscillated by two ball-bearing followers attached to the slides and bearing on opposite edges of the cam. The amplitude of oscillation is 1/2-inch, with 1 traverse of the slides every 1/2 minute. A heating current of 2.8 amperes at 1.4 volts has been found satisfactory. The resulting temperatures are estimated to be in the range of 250° to 350° C. By providing two oscillating slides and special sample plugs it is possible to obtain, simultaneously, duplicate samples for both optical and electron microscope counting.

Advice is needed to collect samples for determing the character of dusts, fumes, and mists with the optical or electron microscope. The electrostatic precipitator has been recognized as having high collection efficiency, and several such samplers have been constructed. An electrostatic precipitator has been reported by Hosey and Jones (27) which is a modification of earlier types incorporating changes based on experience with the earlier types. Four features are incorporated in this modified unit. (a) Samples are collected on glass or metal slides. Glass slides permit direct examination or particle-size measurements without transferring the sample from the inside of the usual metal or glass collecting tube. For examination on the electron microscope, the slides may be coated with suitable material and then lifted and placed on a microscope grid or the grid may be attached to the glass slide. (b) The new sampling head is light weight, transparent, and has a built-in flowmeter. (c) The air flow is at the rate of 1 c.f.m., which permits a smaller head. (d) The power supply operates from 110 volts a.c. or 6 volts d.c. and supplies 60 to 100 m.a. at 300 to 400 volts a.c. to a 15-kv. radio-frequency coil. A variable resistor permits delivery of 8 to 13.5 kv., d.c., to the sampling head. The 6 volts d.c. can be obtained from a motorcycle-type storage battery. The power supply and blower unit draw about 6 amperes at 6 volts. With an air flow of 1 c.f.m., 100 percent efficiency is not obtained with glass slides, but at 0.5 c.f.m. 100-percent efficiency is obtained.

The cascade impactor was designed to grade the sample in a manner to permit analysis of dust by optical or electron microscope. Certain drawbacks to earlier types of an instrument have been found, particularly as it tended to favor the smaller end of the spectrum. This may be due to the design of the instrument. The effectiveness of each stage and, consequently, of the complete instrument will vary with flow rate, so the instrument must be considered as a unit. Wilcox (54) tested three types of instruments and compared the results with the calculated values. For the purpose of collection, a five-stage cascade impactor was designed. As a basis for modification, the Laskin impactor was found the sturdiest available. In the new impactor the first, second, and fourth jets were used as the first, second, and third jets of the new instruments, and two new jets were added.

Samples with a standard geometric deviation as high as 6 were analyzed, and in general the method has shown samples to be more heterogeneous than would be predicted by other methods.

Preparation of dust samples for microscopic sizing is important. M. W. First (21) has noted some of the most important steps to be taken. Particles larger than about 37 microns can be removed by sieving through a 400-mesh screen. Particles cannot be sized down to 0.25 micron with high-powered objectives. The rubbing-out process for producing an even dust dispersion free of agglomerates may be done with a wooden toothpick. The use of viscous mounting mediums, such as gum dammar or Canada balsam dissolved in xylene, not only hastens the process but gives permanent specimens and stops or retards Brownian motion in particles smaller than 1 micron, as well as preventing rapid reagglomeration of the dispersed dust. It is impractical to use a mounting medium having an index of refraction close to that of the particles under investigation, because the visibility of small crystalline particles decreases as the relative index approaches 1.0. A dust should be examined in more than one mounting medium if there is any doubt as to the refractive index of the particles. When there is a wide range of particle sizes on the microscope slide, high magnification and focusing up and down will be required. All particles in each microscope field must be counted so that statistically accurate size determinations can be made. For very light concentrations of fine dust, particles may be sized conveniently by sampling a dust cloud with a membrane filter and sizing under the microscope with an oil immersion objective.

The fatigue caused by counting samples of airborne dust has resulted in search for less fatiguing methods of determining the number of particles of dust without the tedious counting of all particles in the required number of fields. The most-probable-number method has been used chiefly in estimating the bacteriological population, but Chapman (6) has applied it to dust counting. Each square in the Whipple disk can be considered as a sample tube containing inoculated cultures as used in bacterial studies. Each square in the Whipple disk containing no dust is equivalent to a culture tube showing no growth. The method does not alter the standard light-field method of counting, except that the dust is not counted but is estimated statistically. The greatest accuracy is obtained when using a concentration of 600 particles per cubic millimeter for the microprojector and 150 for the microscope. The greatest accuracy is obtained at the point on the distribution curve where the coefficient of variation, expressed as equivalent concentration, is at a minimum. In practice, 125 squares for the microscope and 100 squares for the microprojector have been found to give essentially accurate figures. These squares are scanned by eye, and the scanning is restricted to those squares that appear void at first glance. The correlation coefficient in tests was 0.92; the most probable number generally runs lower than the count. The greatest advantage of the method is the time factor, as the average ratio of count time for one observer in a series of tests was 1.89 and for another it was 3.07.

Great difficulty is experienced in counting dust particles near the resolving power of a microscope, and for that reason the counts of several observers for the same sample often do not agree, although the end result may be within the limits of error. In a like manner the accuracy of counting at the beginning of the day may be higher than near the end of the day, as the eyes become fatigued with counting many threshold particles. Crossmon (13) suggests that using the phase microscope for dust counting may offer a method better than that of the light-field microscope with reference to equipment and technique. When phase microscopy is used, the position of the substage iris diaphragm must be a constant, being at full aperture. The position of the substage condenser is also a constant, being located so as to focus sharply the condenser annulis diaphragm in the plane of the objective annulis. The method of illumination and intensity of light source should preferably be the same as for light-field illumination. A 10X (0.25 N.A.), achromatic, dark-contrast phase objective having a phase-accelerating annulis of 1/4 wavelength of green light and a transmission of 15 to 20 percent is used for counting in combination with a 25X compensating eyepiece. The condenser should be a long-working-distance type of 0.70 N.A. if higher magnification phase objectives, such as the 21X (0.50 N.A.) or 43X (0.65 N.A.), are to be used. The microscope should be focused using the 10X phase objective. The annular stops for the 10X objective is then inserted in the stop holder, the eyepiece removed, and the auxiliary telescope placed in the tube on the microscope. The telescope is focused on the gray ring pattern at the back focal plane of the objective. The brightly illuminated image of the annular stop should be focused sharply in the plane of the gray ring. The condenser is adjusted to a height to register the two annuli patterns perfectly. The telescope is then removed, and the 25X eyepiece is replaced for counting. Small particles usually appear gray and large particles white. Not all dusts lend themselves to counting with the phase microscope, but it is a definite advantage when counting certain mineral dusts.

A sampler for collecting high-volume samples employs a fluted filter. To eliminate the problem of moisture abosorption by the filter during weighing, Humphrey and Morgan (28) place the filter in an aluminum-foil envelope for weighing. Without the foil covering, under average conditions, a dry, fluted filter gains weight at the rate of approximately 0.01 gm. per minute. With the aluminum foil envelope, the total weight gain is only 0.0002 to 0.0004 gm. after 8 minutes on the balance, following a weighing requirement of about 2 minutes.

The theory of thermal precipitation and its applicability to aerosol collectors has been discussed by Poppoff (47) who describes an oscillating type on which some tests were made. The sampling rate is the greatest weakness of the thermal precipitator, as ordinarily 6 to 10 cc. per min. is the acceptable rate. The limiting factors are the narrow flow channel past the hot wire, which is usually 0.010 to 0.015 inch on each side of the wire, and the low linear velocity of approximately 0.04 f.p.s. required for effective precipitation. The moving slides in an oscillating type of precipitator apparently set up extraneous air currents in the narrow channel between the hot body and the sample slides. Tests showed that with oscillation rates greater than 1 f.p.m., collection efficiency was reduced in one model tested. Collection efficiency in a given precipitator is a function of the repulsion velocity; hence, the collection efficiency for two different aerosols can be achieved by adjusting the temperature of the wire to compensate for the difference in thermal conductivities. It is shown that 280° C. is necessary for sampling aluminum oxide with a thermal conductivity of 0.0081 to obtain the same sampling efficiency as when sampling sodium chloride with a thermal conductivity of 0.0136 at 560° C. One of the most important characteristics of any dust-sampling device is its collection efficiency as a function of particle size. Preliminary investigations by Poppoff (47) of the precipitation efficiency of particles less than 1 micron, using alumina powder in the size range 0 to 20 microns at a flow rate of 7 cc. per min. gave collection efficiencies of 100 percent for particles 1-4 microns in diameter, 99 percent for particles 4-6 microns in size, and 98 percent for particles 6-10 microns.

A new filter holder for molecular filter disks for sampling of airborne dusts has been designed at the University of Rochester School of Medicine and Dentistry (36). The model comprises a cylindrical body with a hinged front ring and opposite the hinge, a cam locking bar to enable rapid changing of filter disks (47-mm. diameter). The support for the molecular filters is made of screening to give an even distribution of air flow with a minimum of air resistance. A rubber gasket fitted into the front ring is used to seal the filter disk against an opposing machined seat in the main body of the sampler. A slight lip around this seat positions the filter disk. The molecular filters are given mechanical support by a screen backing inserted behind the seat. A threaded section in the front of the sampler permits using the same filter unit interchangeably with either the cascade impactor or with special sampling probes.

A method for size determinations of dust collected on membrane filters has been developed for the Atomic Energy Commission; the results are reproducible, and the accuracy is good (4). The membrane filter is dissolved in an organic solvent, and the resultant suspension is analyzed turbidimetrically. Determinations by this method, according to Burke, are rapid and easily made.

Samples collected by such instruments as thermal precipitator, cascade impactor, and konimeter have the disadvantage that the number of particles collected must be limited, so that there will not be an excessively heavy deposition. Larger volumes are sampled for a suitable period with such instruments as an impinger, filter, or electrostatic precipitator, and the dust is suspended in a suitable volume of liquid. An aliquot is then examined under a microscope. Certain defects are encountered in counting dust suspended in solution, because, even with relatively insoluble silica, results may be influenced. The length of settling time is also definitely important, and inconsistent results may occur owing to differences in particle size or density of materials involved. To overcome some of these objections, Yaffe and others (56) experimented with molecular membrane filters. With this filter the particles can be counted directly on a microscope; or, if the sample is too dense the filter may be dissolved in a suitable solvent (acetone) and an aliquot of the suspension of the dust examined, using the technique employed for impinger samples. As direct microscopic examination of the sample is more satisfactory than examination of the dissolved material, a study of a comparable method was made. The result was that an aliquot of the dissolved filter and dust was placed on a dry filter. The filter absorbed the liquid rapidly, and the dust was frozen in place. The spot became colorless and transparent, so that the sample could be examined directly on the microscope. It was found that, if too much of the liquid is concentrated on the filter, a hole is produced. It was established that the largest practicable volume was somewhat less than 0.1 ml. Based on these experiments, a method has been developed. The volume must be constant in all samples, and for that purpose a 0.1-ml. syringe used for bacterial count determination was used; this syringe can be certified to be accurate within 5 percent. The volume discharged is regulated automatically. With the syringe, 0.1 ml. of acetone suspension is applied to a dry molecular membrane filter; the subsequent reaction takes place over an area of approximately 1/4 inch. Where it is necessary to dilute a sample, the 0.1-ml. sample can be placed on a dry filter through a 1/4-inch hole drilled in a glass slide or a metal slide. A still better method consists of cutting a circle of filter with a cork borer so that its diameter is slightly more than 1/4 inch. A gummed reinforcing ring with a center hole of 1/4 inch is placed over the small filter disk so that the hole is completely closed and the ring is fastened immediately to a glass microscope slide. A number of filters may be mounted on a single slide. The 0.1 ml. of dust suspension is then placed in the center of the molecular filter. The reaction is instantaneous, and the slide is ready for use.

STATE REGULATIONS ON PNEUMOCONIOSIS

As late as August 1952 Morgis and Davenport (42) reported five States in which the law did not provide compensation for occupational disease. Since then, Oklahoma Workman's Compensation law has added provisions for occupational diseases, including silicosis and asbestosis (29). The law also had been modified by eliminating specific notice and filing limitations in the case of death. It also provides a period of 2 years within which a claim can be reopened. In Michigan an amended law provides for an increase in burial allowance, in awards for permanent total disability, and in the required liability of compensation carriers. The law also rescinds the provision for appointment of a commission of physicians to arbitrate disability disputes. Kansas in 1953 also added silicosis to its compensable occupational diseases.

Mississippi and Wyoming are (January 1, 1955) still without occupational disease laws. The remaining 46 States cover silicosis directly or by general reference. Alabama, Louisiana, and Virginia refer directly to pneumoconiosis, thereby including positively all pulmonary dust diseases; Massachusetts and New York make the same provision by referring to "silicosis and other dust diseases" or "pulmonary" dust diseases. Thirteen States provide only for silicosis, although included in this list is Maine, which provides for "silicosis or its sequelae." Louisiana provides for silicosis and pneumoconiosis. Fifteen States limit the application of compensation to "silicosis or asbestosis;" however, Pennsylvania adds "or anthracosilicosis" to include, particularly, anthracite miners, and Maryland adds the provision of "other pulmonary diseases" by using the phrase "a disease arising out of and in the course of employment." New Mexico and Washington provide compensation for a "disease arising out of the extra hazardous employment." The Washington law phrases it as "such disease or infection as arises naturally and proximately out of extra-hazardous employment."

Alaska, the District of Columbia, and Hawaii provide compensation for occupational diseases arising out of and in the course of employment. Puerto Rico includes silicosis in the list of compensable occupational diseases, "where it has been determined to be the cause of incapacity or death."

The tabulated summary of occupational disease laws (table 2) in regard to pneumoconiosis shows that our States are becoming aware of the part that industrial dusts are playing in the impairment of health in our mines, tunnels under construction, and quarries. It is now up to industries to avail themselves of the knowledge, methods, and equipment available to prevent impairment of health through pneumoconiosis.

OCCUPATIONAL DISEASE LEGISLATION

Ever-increasing interest is being shown in occupational disease legislation, and the mining industry is especially interested in the provisions for controlling dust in mines, tunnels, and quarries and for compensation for those who are disabled by some form of pneumoconiosis. A digest of laws and rules and regulations of the 48 States, the District of Columbia, Alaska, and Hawaii has been compiled by Trasko (52). The compilation necessarily, is limited to selected aspects of occupational health and safety. Brief outlines are given of subjects covered by mining laws, and general provisions of occupational health and safety are given. A study of the topics relating to dust control and compensation will indicate the scope of these laws in each State and where more detailed data are desired, the laws can be obtained by communicating with the appropriate State agency.

TABLE 2. - State compensation or occupational disease laws referring to pneumoconiosis

State	Pneumoconiosis	Silicosis	Silicosis and other diseases	Silicosis or asbestosis	Injury or diseases arising out of and in the course of employment	Arising out of conditions which are characteristic and peculiar to a particular trade, process, or employment	Disease arising out of extra hazardous employment	None
Alabama	X							
Arizona				X				
Arkansas				X				
California					X			
Colorado				X				
Connecticut ...					X			
Delaware					X			
Florida						X		
Georgia				X				
Idaho		X						
Illinois					X			
Indiana					X			
Iowa		X			X			
Kansas		X						
Kentucky		X						
Louisiana	X	1/X						
Maine		2/X						
Maryland				3/X				
Massachusetts..			X					
Michigan					X			
Minnesota				X				
Mississippi ...								X
Missouri					X			
Montana		X						
Nebraska						X		
Nevada		X						
New Hampshire..					X			
New Jersey				X	X			
New Mexico					X			
New York			X					
North Carolina.				X				
North Dakota...						4/X		
Ohio		X						
Oklahoma				X				
Oregon				X				
Pennsylvania ..				5/X				
Rhode Island ..				X				
South Carolina.					X			
South Dakota...		X						
Tennessee				X				
Texas				X				
Utah		X						
Vermont				X				
Virginia	X							
Washington							X	
West Virginia..		X				X		
Wisconsin		X						
Wyoming								X

1/ Silicosis and pneumoconiosis. 2/ Or its sequelae.
3/ Or other pulmonary dust diseases. 4/ Any disease fairly traceable to the employment. 5/ Or anthracosilicosis.

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